

**ATOMIC FORCE MICROSCOPE AND METHOD FOR DETERMINING
PROPERTIES OF A SAMPLE SURFACE USING AN ATOMIC FORCE
MICROSCOPE**

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BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to conductive probe
microscopes, and more particularly to atomic force
microscopes.

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2. Government Funding

Funding for this invention was provided by the U.S.
Government under DARPA contract number MDA972-99-C-0009

3. Description of the Related Art

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Scanning probe microscopy, such as conductive atomic
force microscopy (CAFM), is widely used for observing and
analyzing sample surfaces in the atomic scale. One
conventional example of an atomic force microscope (AFM)
uses a probe that has a microfabricated tip mounted on a
flexible cantilever. The tip is typically made from Si_3N_4 or
Si. The tip is slowly scanned across the surface of a
material, just a few angstroms away from the surface
(non-contact mode) or in contact with it (contact mode). The
force between the atoms on the surface of the material and
those on the tip cause the tip to deflect. The magnitude of

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the deflection depends on the separation between the surface atoms and the tip atoms and on the atomic forces between them, such as van der Waals forces or Pauli exclusion forces. This deflection can be recorded in various ways, the most common of which uses a laser focused on the top of the cantilever and reflected onto photodetectors. The photodetector signals are used to map the surface topography of samples with resolutions down to the atomic and nano scales. The lateral and vertical movements of the tip or sample are controlled by piezoelectric transducers and a feedback loop that produce voltage differences proportional to the movement.

After mapping a microscopic feature of interest, such as a sub-micron magnetic tunnel junction, the conductive tip can be used to make an electrical measurement of the feature. The tip is centered over the feature and then the x-y scanning is stopped. The tip is then lowered into contact with the feature. After contact is made, current can be passed through the feature to make an electrical measurement.

During the process of lowering the tip into contact with the feature, the tip usually must be pushed onto the sample surface progressively harder until electrical contact is made. This causes the tip to wear out rapidly, usually

after only a few contacts. Further, the downward force on the tip required to maintain electrical contact between the tip and the sample surface can damage the sample.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an atomic force microscope and method for determining properties of a sample surface using an atomic force
5 microscope that reduces tip wear.

Another object of the present invention is to provide an atomic force microscope and method for determining properties of a sample surface using an atomic force microscope that eliminates or reduces damage to the sample
10 surface.

A method for determining properties of a sample surface using an atomic force microscope according to an exemplary embodiment of the invention includes applying a first voltage between the sample and a probe, moving the probe
15 towards the surface of the sample, and stopping movement of the probe towards the surface of the sample when current in the probe is initially detected. A magnetic field is applied to the probe such that the probe obtains stable contact with the surface of the sample.

20 A method according to at least one embodiment of the invention includes oscillating the magnetic field applied to the probe.

An atomic force microscope that determines characteristics of a surface of a specimen according to an

exemplary embodiment of the invention includes means for applying a first voltage between the sample and the probe, means for moving the probe towards the surface of the sample, means for stopping movement of the probe towards the surface of the sample when current in the probe is initially detected, and means for applying a magnetic field to the probe such that the probe obtains stable contact with the surface of the sample.

An atomic force microscope according to at least one embodiment of the invention includes a means for oscillating the magnetic field applied by the means for applying a magnetic field.

These and other objects, features and advantages of the present invention will become apparent from the following detailed description of illustrative embodiments thereof, which is to be read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

The invention will be described in detail in the following description of preferred embodiments with reference to the following figures wherein:

- 5 Fig. 1 shows an atomic force microscope according to an exemplary embodiment of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

In the method of performing atomic force microscopy according to various exemplary embodiments of the invention, a probe is lowered in contact with the surface of a sample until current begins to flow between the probe and the sample. A magnetic field is then applied to the probe and sample. The magnetic field is oscillated rapidly, causing the AFM probe to move such that the probe makes excellent stable contact with the surface of the sample. Probe wear is reduced because the probe does not need to be forcefully pushed onto the surface to initiate and maintain electrical contact.

FIG. 1 shows an atomic force microscope according to an exemplary embodiment of the invention. The atomic force microscope 1 includes a piezoelectric scanner 10, a stage 30, a current-to-voltage converter 40, an amplifier 50, a controller 60, a voltage source 70 and a magnetic field source 80. The piezoelectric scanner 10 includes a piezoelectric tube 12. The piezoelectric tube 12 includes an X-piezo element 14, a Y-piezo element 16 and a Z-piezo element 18, which move the probe in the X, Y and Z directions, respectively. According to the present embodiment, a probe 90 is attached to the bottom of the piezoelectric tube 12. However, it should be appreciated

that, in other exemplary embodiments of the invention, the piezoelectric tube 12 can be attached to the stage 30. The probe 90 is formed from any suitable material, such as, for example, silicon nitride.

5 During a specimen measurement, a sample 100 is placed on the stage 30. The sample 100 can be, for example, a semiconductor device including sub micron circuit features. The voltage source 70 applies a known voltage to the sample 100. The controller 60 then actuates the piezo-electric
10 scanner 10 to lower the probe 90 in the z-direction onto the sample 100 until current in the probe 90 is detected by the controller 60. It should be appreciated that, in other embodiments in which the piezoelectric tube 12 is attached to the stage 30, the probe 90 is held stationary in the
15 z-direction and the stage 30 is raised until electrical contact between the sample 100 and the probe 90 is initiated.

 Once current begins to flow through the probe 90, movement of the probe 90 (or stage 30) in the z-direction is
20 stopped, and the controller activates the magnetic field source 80. The magnetic field source 80 can be any suitable magnetic field source, such as, for example, a magnetic coil. The magnetic field source 80 applies an oscillating magnetic field to the probe 90, causing the probe 90 to move

in such a way that the probe 90 makes excellent stable contact with the sample 100. The magnetic field can be oscillated with an amplitude of, for example, 200 Oe and a frequency of, for example, 5 Hz for a duration of, for example, 2 cycles.

The current induced in the probe 90 by the voltage source 70 is fed along line 42 to current-to-voltage converter 40. A voltage output passes along line 52 from current-to-voltage converter 40 to amplifier 50. The amplifier 50 amplifies the voltage output, which is then input to the controller 60. The controller 60 can be any suitable controller, such as a user-accessible computer 62 including a monitor 64. The voltage outputs collected by the computer can be used to display various imaging maps of the surface topography of the sample 100 on the monitor 64. For example, simultaneous mapping of topography and local current signal can be achieved, and regions of higher and lower conductivity can be differentiated to correlate with topography

It should be appreciated that, in other embodiments, the atomic force microscope according to the invention can have any other suitable configuration that includes a magnetic field generator that applies a magnetic field to the probe. For example, the probe can be disposed at an end

of a piezoelectric cantilever beam. Further, according to
at least one embodiment, the atomic force microscope
according to the invention includes a laser beam and
photodetectors to record the movement of the probe as the
5 probe is scanned across the sample surface.

Although the illustrative embodiments have been
described herein with reference to the accompanying
drawings, it is to be understood that the present invention
and method are not limited to those precise embodiments, and
10 that various other changes and modifications may be affected
therein by one of ordinary skill in the related art without
departing from the scope or spirit of the invention. All
such changes and modifications are intended to be included
within the scope of the invention as defined by the appended
15 claims.